

# PATENT SPECIFICATION

DRAWINGS ATTACHED

1,099,085

Date of Application and filing Complete  
Specification: February 21, 1966.

No. 7513/66

Complete Specification Published: January 17, 1968.

© Crown Copyright 1968.



1,099,085

Index at Acceptance:—F1 F (1J, 2D, 2F, 2G2, 2N1A, 2Q); B3 D2A9; B3 K (2A4J, 2A8A, 7B8AX, 7B8X, 7M); B3 L (2A, 3F).

Int. Cl.:—F 01 c 3/00.

## COMPLETE SPECIFICATION

### Rotary Positive Displacement Units

I, ERNEST WILDHABER, a citizen of the United States of America, of 124 Summit Drive, Rochester, New York, United States of America, do hereby declare the invention for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

10 The present invention relates to rotary positive-displacement units. The unit may be embodied as a compressor, a pump, a motor or engine, and as a unit combining a compressor and a motor. A unit referred to comprises at least a housing, a pair of rotors with interengaging lobes or teeth designed for mesh all around their periphery, and ducts for leading fluid to and from the rotors. The pair of interengaging rotors have numbers of lobes or teeth that differ by one.

20 Pumps of this general description are known with rotors that run on parallel axes, and where one rotor has teeth provided on its outside periphery while the other rotor surrounds said one rotor and has teeth provided internally thereon. Such known structure is limited in tooth depth, which is bound to be the circular pitch divided by  $\pi=3.1416$ . This limits the displacement, and there are other limitations.

25 One object of the present invention is to devise a unit of the character referred to which is not thus limited, and where the lobe depth is larger than one third of the circular pitch, usually much larger. A further object is to devise a unit whose rotors can run at very high speed and which can stand far more centrifugal inertia loads than the internally toothed member of known design. A further aim is to devise a unit with a pair of rotors which expand more nearly in a direction lengthwise of the

lobes when run at high temperature, so as to remain well matched.

35 In the known rotors with parallel axes, contact is mainly with the sharply curved end surfaces of the teeth. These contact side surfaces or each other. A further and important aim is to devise a unit wherein the side surfaces themselves of the mating lobes are adapted to contact each other, and to contact so as to have a duration of contact between side surfaces larger than one pitch. These mating side surfaces are only moderately curved away from one another and can carry considerable load. A still further aim is to devise a unit for gases or air, that can be run at very high speed without requiring timing gears, and where the lubrication provided on the side surfaces of the lobes by the gaseous fluid is sufficient to carry the loads sustained.

40 A still further object is to provide a unit embracing a compressor and a motor or engine of different volume displacement, where one of the pair of rotors of the compressor is rigid with one of the pair of rotors of the motor.

45 Other objects will appear in the course of the specification and in the recital, of the appended claims. These objects may be attained singly or in any combination. They are attained with rotors whose axes intersect at an angle.

50 In the accompanying drawings:

55 Fig. 1 is a diagram explanatory of the principles underlying the present invention. Fig. 2 is an axial section of a unit constructed according to the present invention.

60 Fig. 3 is a section through the casing of this unit, taken along lines 3-3 of Fig. 2.

65 Fig. 4 is an axial section of a modified unit.

70 Fig. 5 is an axial section, partly a side

Best Available Copy

view, of a rotor of modified design.

Fig. 6 is an axial view of a rotor constructed according to the present invention, looking at its face, showing its straight lobes or teeth directed towards its apex.

Fig. 7 is a similar axial view, showing lobes curved lengthwise.

Fig. 8 is an axial view of a modified rotor showing lobes curved lengthwise and spirally inclined.

Fig. 9 is a diagram illustrating one way of producing rotor lobes or teeth constructed according to the invention. It shows the rotor in axial section.

Fig. 10 is a similar diagram employing reciprocating tool motion.

Fig. 11 is an axial section of a rotor and a diagrammatic view of tool means corresponding to Fig. 10, looking in the direction of the tool motion. The tool is shown in a position cutting or grinding the lobe bottom.

Fig. 12 is a view looking in the direction of the tool motion when the tool engages the side of a lobe. Fig. 12 corresponds to Figs. 10 and 11 and shows the rotor in a diagrammatic view in a tilted position.

Fig. 13 is a diagrammatic view like Fig. 12, but illustrating a different tool profile.

Fig. 14 is an enlarged view of the rotors shown in Fig. 2, looking at right angles at the plane of their axes.

Fig. 15 is a fragmentary view thereof taken in the direction of the instantaneous axis (32 in Fig. 2) and showing the fully engaged lobes.

Fig. 16 is a fragmentary view looking along the line of contact of the lobe ends, taken along line 39 of Fig. 2.

Fig. 17 is a diagrammatic view of a unit comprising a compressor and a motor or engine.

Fig. 18 is a diagrammatic section taken along lines 18-18 of Fig. 17.

Figs. 19 and 20 are diagrams illustrating the advantage obtained in inclining the plane of the axes of each of the two rotor pairs with respect to each other. They can be considered sections along lines 19-19 of Fig. 17, looking in the direction of the arrows.

In the diagram Fig. 1, numerals 30, 31 denote the rotor axes intersecting at apex O. The rotor with axis 31 has any number N of lobes or teeth, while the rotor with axis 30 has (N+1) lobes or teeth. As the rotors run at the ratio of their tooth numbers, there is a fixed axis 32 of instantaneous relative motion. It can be considered the line of contact of conical pitch surfaces which move with the rotors and roll on each other without sliding. Any point 33 of the instantaneous axis 32 has distances from the axes 31, 30 in proportion to the tooth numbers N, (N+1).

Let  $s$  denote the angle between the axes

30, 31 and  $p$  the inclination of instantaneous axis 32 to the vertical. The pitch angles 28, 29 of the two rotors are then  $(90^\circ - s - p)$  and  $(90^\circ + p)$ . The distances of point 33 from the axes 31, 30 can then be expressed as  $(0-33) \cdot \cos(s+p)$  and  $(0-33) \cdot \cos p$  respectively.

Their proportion  $\frac{\cos(s+p)}{\cos p}$  equals 75

$$\frac{N}{(N+1)} = m.$$

As known this can be transformed into 80  $\frac{\cos s - m}{\cos s} = \frac{N}{(N+1)}$

$$\tan p = \frac{\sin s}{\cos s - m}, \text{ where } m = \frac{N}{(N+1)}$$

It will now be shown numerically how much more lobe depth is attainable with intersecting axes than with parallel axes.

For instance at a ratio of the lobe numbers of  $(N+1)/N = 9/8$ , angle  $p$  equals  $16^\circ 35'$  at  $s = 15^\circ$ . The tooth depth  $2s$  is then  $30^\circ$ , measured on a great circle. The angular pitch, also measured on a great circle is  $\frac{360^\circ}{9}$ .

$\cos p = 38^\circ 20'$ . The proportion of lobe depth to pitch is  $30/38.33 = 95/100$ .

With parallel axes of the rotors the pitch circle circumferences differ by the circular pitch, and the pitch circle diameters differ by the circular pitch divided by  $\pi$ . The tooth depth equals the difference in pitch circle diameters. The proportion of tooth depth to circular pitch is thus unavoidably  $1/\pi = 1/3.1416$ . It is less than one third.

The depth proportion has a profound influence on the lobe shape attainable, and of course the larger proportion increases the displacement.

The rotors 34, 35 (Fig. 2) with axes 30, 31 are rotatably mounted in a housing 36 formed by two parts tightly bolted together. The rotors have convex outer surfaces lying in a common spherical surface 37 that is centred at apex O at which the axes 30, 31 intersect. This surface matches a counterpart concave spherical surface provided in housing 36. The counterpart surface serves as a seal and is interrupted by ducts 38, 38'. When Figs. 2 and 3 refer to a compressor, the outlet pressure is higher than the inlet pressure and the outlet area is more confined. 38 is the inlet, 38' the outlet for a compressor. On a motor or engine the inlet pressure is higher, and the inlet area is more confined. Looking at Fig. 3, rotation is in clockwise direction for a compressor, in counter-clockwise direction for a motor.

At their inner ends the lobes 45, 46 bear against or match a spherical surface por-

tion 40 also centered at O. This portion is formed integral with a cylindrical portion 41 and shaft 42. Rotor 34 is made rigid with shaft 42 by lateral projections that engage slots 43 provided on a flange 44 of shaft 42.

Figs. 14 to 16 afford enlarged views of the rotors 34, 35. Their interengaging lobes 45, 46 form pockets 47, 47', 47''... of changing volume. When rotation is in direction of arrow 48 the pockets diminish in volume. On a compressor the outlet area starts in a region where the volume has been substantially decreased.

#### Profiles

I may start a design by assuming the lobe numbers  $N$ ,  $(N+1)$  and the angle  $s$  between the shafts. This determines the angular lobe depth, which is  $2s$ . Next I may determine the axes of curvature of the convex outer lobe ends, and particularly their angular distance from each other when they contact at their outer ends (Fig. 16). The lobe surfaces now considered are composed of straight-line elements that all pass through apex O. The end surface portion lies either in a circular conical surface or in a surface whose curvature at the end coincides with that of a conical surface. In one embodiment the end-surface portion 46e (Fig. 14) of rotor 35 having  $N$  lobes is part of a circular conical surface. Fig. 1 shows the axis 50 of this conical surface in the position where it lies in the plane of the axes 30, 31. It includes an angle  $b$  with the instantaneous axis 32. 50' shows the position of axis 50 after rotation about rotor axis 31 through half a turn, so that it again lies in the plane of the axes 30, 31, the drawing plane of Fig. 1. The curvature axis 51' of the lobe end 45e of rotor 34 includes an angle or arc  $b'$  with curvature axis 50'. This arc is preferably smaller than half the circular pitch, measured as an arc on a great circle whose plane passes through O.

The following formula can be derived for the angle  $b'$  with the methods of spherical trigonometry:

$$\tan b' = \frac{P \sin^2 c}{1 + P \sin c \cos c}$$

wherein  $P = \tan(s+p) - \tan p$   
and  $c = 2(s+p) - b$

Angle  $b$  is changed until  $b'$  attains a desirable amount.

After assuming the lobe end 46e of rotor 35 and its axis of curvature 50 the entire surface of the lobes 45 can be determined as the surface enveloped by this lobe end when it is turned about axis 31 while rotor 34 turns on its axis at the ratio of the tooth numbers or lobe numbers  $(N+1)$  and  $N$ , so that the conical pitch surfaces roll on each other without sliding.

When the assumed tooth end 46e is a circular conical surface, it can be embodied by a conical milling cutter or grinding wheel whose axis coincides with axis 50. When the axis of this tool is moved relatively to a rotor 34 as stated above, the rotating tool will produce the lobes thereof.

During such motion axis 50 (Fig. 1) describes a conical surface, and its point 53 traces a circle 53' showing up as a straight line. Contact between rotor 34 and the conical end surface of rotor 35 is always in a plane that connects the instantaneous axis 32 with the considered position of axis 50. It is along the cone element that lies in said plane, the normal plane of said element. Broadly contact is in a turning position where the normal plane of a considered straight-line element passes through and contains the instantaneous axis. The said plane is then a contact plane, common to both rotors.

The desired tooth thickness is attained by changing an initial assumed cone angle of the end surface.

It should be noted that the side surfaces 45s have a desirable moderate inclination to axial planes, that is to planes containing axis 30. This is a result of the increased lobe depth. The side profiles, the profiles of the side surfaces 45s, are inclined less than thirty degrees to the axial plane (49, Fig. 15) passing through their mid-portion.

The side surfaces 45s contact the end surfaces 46e of rotor 35, and they have a further position of contact. The said contact plane passes through the instantaneous axis 32 a second time in its rotation about axis 30. In the second position contact is between the lobe sides 45s, 46s, of the rotors 34, 35. This is also apparent from consideration of Fig. 15. Obviously the sides 45s, have mating lobe sides 46s. The contact position for the sides can be computed with the known procedures of spherical trigonometry. Knowing the contact position and the line of contact the mating shape itself can be readily determined. Line 54 (Fig. 15) is the path of contact between the lobe sides 45s, 46s. Line 54' is the path of contact for the opposite lobe sides. It is seen that the duration of contact obtained with path 54 is larger than one full pitch, as the lobes are relatively deep. Always at least one pair of lobes contact with their side profiles, on each of the two opposite lobe sides. Because of the moderate relative curvature of the side profiles a considerable load can be carried at all times, even under adverse conditions of lubrication, or with lubrication by gaseous fluid only.

Dotted line 54s is the path of contact of the lobe ends 46e.

33-33s, Fig. 2, is the lobe addendum of rotor 34; and 33-33s, is the lobe dedendum

thereof. While the addendum is smaller than the dedendum in the example illustrated, it may also be made larger than the dedendum in many cases.

- 5 In the embodiment of Figs. 2 and 3 the outlet opening and the inlet opening are both provided adjacent the outer end of the rotor lobes, at the spherical surface 37.

#### *Modified Embodiments*

- 10 Fig. 4 illustrates an embodiment with inlet opening at the inner spherical surface 40 and outlet opening at the outer spherical surface 37. This embodiment may be used, for instance, on pumps, where the centrifugal action adds to the effect. The rotors 34', 35' with axes 30, 31 have the described shape. They are rotatably mounted in a housing 55 to which is rigidly secured a tubular member 56 with rounded end 56'.  
 15 This end contains the described inner spherical surface portion 40 on its outside and an adjacent cylindrical surface portion 41' which serves as a journal for rotor 34'. Fluid enters along axis 30 and through  
 20 openings 57 provided in end 56'. Outlet duct 58 leads to an outlet not shown.

- In the embodiments so far illustrated the inner spherical surface 40 has about half the diameter of the outer spherical surface 37. If the lobes or teeth were continued all the way to apex O, the volume displaced inside of surface 40 would be only one eighth of the volume displaced inside of surface 37 of double diameter. With lobes  
 25 having their inner ends at surface 40 the displacement is still 7/8 of the maximum displacement possible inside of surface 37, while a material advantage is gained in the production by cutting or grinding. However when production is for instance by  
 30 moulding, coining or casting the production advantage is reduced and I may diminish the inner spherical end surface to almost nothing. Fig. 5 shows a rotor 34" so shaped.  
 35 The inner spherical surface 40, has less than half the radius of the outer spherical surface 37, and the knob containing surface 40, is formed integral with rotor 34".

- Proportionately small inner spherical  
 40 surfaces may also be provided on rotors of large size, and on rotors intended for extreme rotational speeds where the increased production cost is acceptable.

- Fig. 6 is an axial end view of a rotor 34, that may be used as rotor 34 in the described units. It has straight lobes or teeth 60 directed towards apex O, at which the axes of the rotor pair intersect. The surface of its lobes is made up of straight-line elements, all passing through apex O.  
 45 The inner spherical surface 40, has less than half the radius of the outer spherical surface 37, and the knob containing surface 40, is formed integral with rotor 34".

- Fig. 7 is an axial view of a rotor 34, whose lobes 60, are curved lengthwise, chiefly for a production advantage in medium and small sizes. Opposite lobe  
 50 sides 61, 61' are convex and concave length-

wise, respectively. At their mid-portion the lobes are directed towards apex O.

The rotor 34, shown in Fig. 8 has longitudinally curved lobes 60, that are spirally arranged. Spirally arranged lobes may be considered especially in the embodiment described with Fig. 4. The types illustrated in Figs. 6 to 8 can each be used in both described embodiments.

If desired, I may use blades or vanes in the inlet and outlet passages, to direct the fluid more positively.

#### *Production*

One way of producing a rotor 34 with straight radial lobes in a generating operation has already been described. There a conical milling cutter or grinding wheel describing (reproducing) a tooth end of rotor 35 is caused to roll on rotor 34 as if it were a part of rotor 35. The mating  
 55 rotor 35 may be cut with the same conical milling cutter as used in cutting rotor 34 in a similar rolling motion. Here however the turning motion about the two intersecting axes is at a varying ratio. A timing  
 60 change is introduced for instance by cam means.

Another method, also suited for large sizes, will now be described with reference to Fig. 9. It uses a conical milling cutter 62 or grinding wheel similar to that used in cutting rotor 34. The axis 63 of the cutter used intersects the axis 30 of the rotor blank 34, at apex O. The cutter 62 is rotated on its axis for stock removal while the workpiece 34, is slowly turned on its axis 30 and while the cutter is fed about apex O. It is fed about an axis intersecting the workpiece axis at apex O and that may be perpendicular to axis 30 and to the drawing  
 65 plane. Another position of cutter 62 during its feed motion is shown in dotted lines 62'. The feed motion of the cutter is at a varying ratio to the turning motion of the workpiece. It is a slow oscillating motion between two end positions timed to the turning motion of the workpiece. While the turning motion of the workpiece can be at a uniform rate, a better production rate is attained by cyclically varying the speed of the feed motion.

The mating rotor 35 may be produced with the same cutter and the same method, using a different timing between the turning motion of the workpiece and the angular  
 70 feed motion between the cutter and workpiece.

Figs. 10 to 12 illustrate a method using tool reciprocation. Edged tool 64 or grinding wheel 64' has a convexly curved working  
 75 profile 65 or cutting edge, that is at least as much curved as the concave bottom profile of the rotor at the inner lobe end. It is a circular arc centered at 67 (Fig. 11). The sides 68 merely serve to support the

working profile without contributing to the shape produced. Tool 64 or wheel 64' is reciprocated lengthwise of the lobes towards and away from apex O along line 70. Line 70 lies in the plane of Fig. 10 and is perpendicular to the drawing plane of Figs. 11 and 12. Figs. 10 and 11 show the position where the tool cuts the lobe bottom along line 70. To produce the side surfaces of the lobes, the workpiece 34 is fed angularly about an axis 59 passing through apex O and perpendicular to the drawing plane of Fig. 10. Dotted lines 34' show the workpiece in a tilted position where a straight-line element of the lobe side is produced. This cutting position is also shown in Fig. 12.

To cut or grind along a fixed line 70 all the time, the cutting tool or grinding wheel is fed in a circular path 72 about an axis coinciding with line 70, at such a rate that the profile inclination of the tool at line 70 coincides continuously with the profile inclination of the workpiece. This additional feed motion of the tool may be a circular translation, where the tool remains parallel to itself, and where center 67 describes arc 72. The said additional motion is timed with the turning motion of the workpiece. The angular feed motion between the workpiece and tool is also timed with said turning motion, again at a varying rate.

Production advantages are gained by periodically varying the speed of the feed motions. The process is continuous. The workpiece is fed in and out about axis 59 once for each lobe. The lobes are completed after the workpiece has made a full turn.

Grinding wheel 64' should be small enough to clear the workpiece 34 on the far side. The size restriction is less severe when the larger rotor 34 of the pair has an uneven number of lobes. Then a lobe space is diametrically opposite a lobe; and the grinding wheel can reach somewhat into a lobe space when grinding the outside end of a lobe.

Roughing may be accomplished with a rotary cutter 64" (Fig. 10) of the same profile shape, without reciprocation but with the same feed motions.

Spiral teeth may be produced by adding a continuous turning motion of the workpiece and timing the reciprocations with said added motion.

Fig. 13 illustrates a working profile 73 of varying curvature. It is convex and most curved at its end 74 and less curved on both sides 75. It can be used on a reciprocating tool or grinding wheel or also on a tool 76 that oscillates about an axis 77 for cutting. In the latter case the mating rotor 35 with convex face surface may be cut with a rotating cutter that turns about axis 77.

Axis 77 lies in a plane perpendicular to

line 70. The said additional tool motion is in this plane and is such that the tool profile 73 always passes through the fixed point at which line 70 intersects said plane. This additional tool motion is so timed with the turning motion of the workpiece that the tool profile has the same inclination as the lobe profile passing through said fixed point, so that the two profiles contact at said point. Except for the additional tool motion, the feed motions are the same as in the method described with Figs. 10 to 12. They are such that fixed line 70 describes the lobe surfaces.

While the additional tool motion for working profiles (73) of varying curvature is more complex than for circular arcuate working profiles, there is less tool wear, improved finish of the lobe sides and improved production efficiency.

The described lobe shape is furthermore singularly well adapted to finishing by shaving, burnishing and lapping because of the many simultaneous contacts all around the circumference.

#### Multiple Rotor Pairs

Diagram Fig. 17 shows a disposition of a unit with two pairs of rotors 80, 81 and 82, 83 of different volumetric displacement rotatably mounted in a housing 84. It can be embodied as an engine unit or also as a cooling unit. In an engine unit the rotors 80, 81 are part of a compressor. Duct 85 admits air to the compressor. Duct 86 leads the compressed air to a combustion chamber diagrammatically indicated at 88. Duct 89 leads the combustion gas to the other pair of rotors 82, 83. An exhaust duct 90 leads the expanded combustion gas therefrom to the outside.

The angularity of the rotational axes 91, 92 of rotors 80, 81 is smaller than the angularity of the axes 92, 93 of the rotors 82, 83. The rotors 81, 82 have a common axis 92 and are rigid with each other. Furthermore the plane of the intersecting axes 91, 92 is preferably inclined to the plane of the intersecting axes 92, 93 to achieve improved pressure balance between the rotors 81, 82. The reason for this inclination will now be shown with Figs. 19 and 20.

Fig. 19 illustrates the load conditions when the axes 91, 92, 93 are all in one plane. The compressed air exerts a one-sided pressure on rotor 81. This pressure may be along an arrow 94 shown in Both Fig. 17 and Fig. 19. It intersects the mid-plane 78 of shaft portion 78' at a point 79. A similar one-sided pressure is exerted on rotor 82. It may extend in the direction of arrow 95 that intersects plane 78 at 96. The length of the arrows are measures of the loads. The axial pressure components through points 79, 96 partly balance each other, but they also produce a turning moment in a 130

plane parallel to axis 92 containing points 79, 96. The turning moment increases with increasing distance of the points 79, 96 from one another. The load components in mid-plane 78 can be combined to a resultant 92-97 (Fig. 19) which passes through axis 92 plus a turning moment about said axis. The turning moment is the difference of the turning moments exerted by the loads passing through the points 79, 96.

Fig. 20 shows the effect of a displacement of the plane of the axes 91, 92 about axis 92. Displacement is through an angle which moves point 79 to a position 79' close to point 96. The resultant load 92-97' in mid-plane 78 is slightly smaller than load 92-97. But the main gain lies in the sharp decrease of the turning moment exerted by the axial load components passing now through points 96, 79', because of the proximity of these points. Diagram Fig. 17 should be understood to correspond to the showing of Fig. 20.

The resulting turning moment about axis 92 is relatively small. The torque exerted on rotor 82 of the motor drives the compressor. Only a moderate portion thereof is transmitted through the lobe sides in the rotor pair 82, 83.

In operation the air is compressed in the rotor pair 80, 81 to a degree controlled by edge 87 (Fig. 17) of the outlet opening. This pressure is maintained in the combustion chamber, where combustion expands the volume of the gaseous fluid. The rotor pair 82, 83 thus requires a larger displacement volume, which is built into the diameter of the rotors and into the angularity of their axes.

When the amount of fuel injected in to the combustion chamber is diminished under the design amount, the expansion through combustion decreases, and the pressure in the combustion chamber decreases. The compressed air then expands after leaving the compressor, increasing its volume, until the further increase in volume through combustion equals the volume displaced in the rotor pair 82, 83.

A gain in efficiency at reduced or changed engine load can be achieved by changing the outlet opening of the compressor for different loads, increasing the outlet area when fuel admission is decreased. This changes the pressure directly, without requiring expansion of the compressed air when leaving the compressor.

Figs. 17 and 18 diagrammatically illustrate means for changing the outlet opening of the compressor. Edge 87 of the outlet opening is provided on a part 98 that can be angularly adjusted about axis 91 in dependence of the fuel admission. Dotted lines 98' show part 98 after adjustment for a decrease in compression and decrease in

fuel admission. Edge 87 is then at 87'. The displacement of the opposite end 98, has little effect on the performance, because there is practically no change in volume in that region.

Cooling of the hot parts may be provided in any suitable known way.

When the unit shown in Fig. 17 is embodied as a cooling unit, the larger rotor pair 82, 83 takes the incoming fresh air 75 and compresses it. The air thereby heats up and is transmitted to a cooler, or broadly to a thermal part 88 for changing the temperature of the gaseous fluid. After cooling it is led to the rotors 80, 81 which now serve as a motor. As it expands therein the temperature drops to the level for which the unit was designed. A stream of cool fresh air leaves the unit.

#### WHAT I CLAIM IS:—

1. A positive displacement unit usable, for example, as a compressor, motor or pump, comprising a housing, a pair of rotors rotatably journaled in said housing and having interengaging lobes or teeth, which mesh around the whole of the peripheries of the rotors, the number of lobes or teeth in the two rotors differing by one, and the rotary axes of the two rotors being inclined to one another.

2. A positive displacement unit as claimed in claim 1, wherein the depth of the lobes or teeth of each rotor in an axial plane of each rotor is larger than one third their circular pitch.

3. A positive displacement unit as claimed in either claim 1 or claim 2, wherein the teeth of the rotors are straight and converge to the point of intersection of the rotor axes.

4. A positive displacement unit as claimed in any of the preceding claims, wherein the rotors have convex spherical outside surfaces which lie in a common convex spherical surface, the housing has inlet and outlet openings, and at least the outlet opening lies on this common spherical surface.

5. A positive displacement unit as claimed in claim 4, wherein the inlet opening also lies on said common spherical surface.

6. A positive displacement unit as claimed in claim 4, wherein the rotors have also spherical concave surfaces which lie in a common inner spherical surface, and the inlet extends through this inner spherical surface.

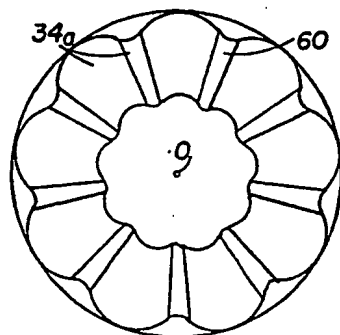
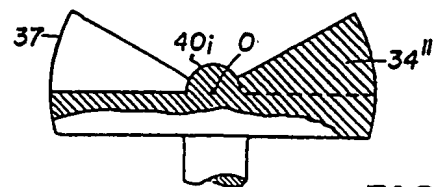
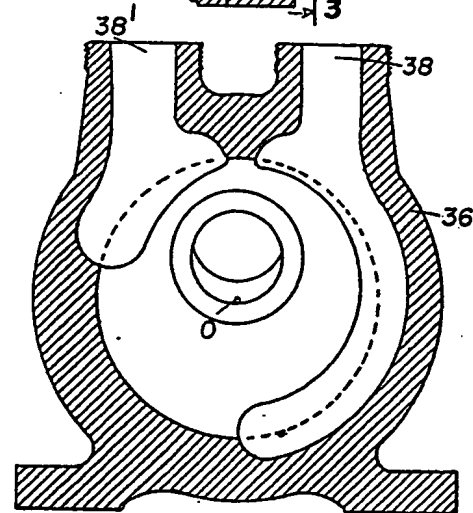
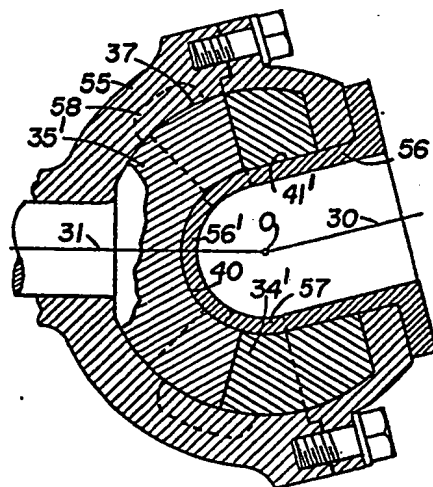
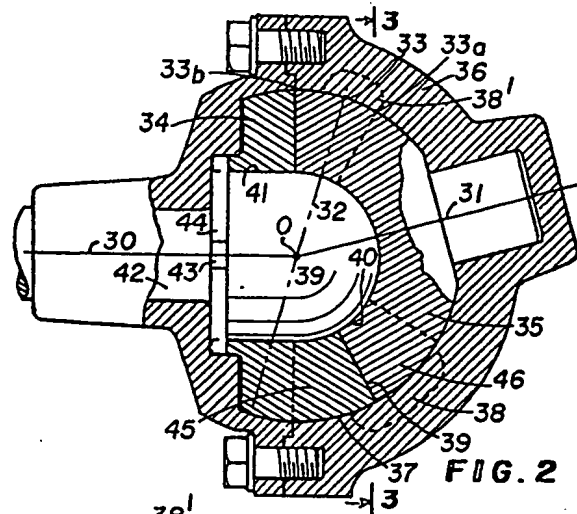
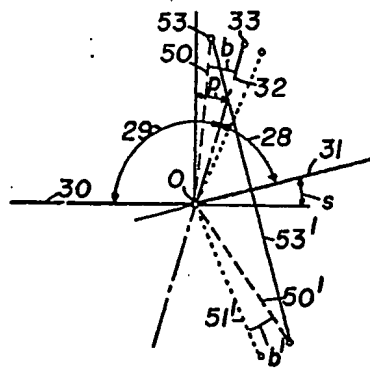
7. A positive displacement unit as claimed in any of the preceding claims, wherein the lobes or teeth of both rotors have rounded tops adapted to come into contact, and the radius of curvature at the center of the tooth tops of both rotors is less than half the circular pitch.

8. A positive displacement unit as

- claimed in claim 7, wherein the lobes or teeth of one rotor, which is smaller, have a conical outer surface whose axis passes through the point of intersection of the rotor axes.
9. A positive displacement unit as claimed in any of claims 4 to 8 inclusive, wherein the inlet opening is adjustable.
10. A positive displacement unit as claimed in any of the preceding claims, wherein the lobes or teeth of the rotor pair are curved lengthwise.
11. A positive displacement unit as claimed in any of the preceding claims, wherein the lobes or teeth have side portions inclined to axial planes of the respective rotors by less than thirty degrees and more curved top portions and bottom portions, said lobes or teeth being deep enough so that their mating side portions have a duration of contact in excess of one pitch.
12. A positive displacement unit as claimed in any of the preceding claims wherein one rotor has a pitch angle larger than a right angle, and the other rotor has profiles with convex circular arcuate tops.
13. A positive displacement unit as claimed in any of the preceding claims, wherein there are two pairs of rotors such as claimed, and one rotor of one pair is coaxial with one rotor of the other pair and is fixedly secured thereto.
14. A positive displacement unit as claimed in claim 13, wherein the intersecting axes of one pair of rotors is inclined to the plane of the axes of rotation of the other pair.
15. A positive displacement unit as claimed in claim 13, wherein the intersecting axes of one pair of rotors includes an angle which is different from the angle included between the axes of the other pair.
16. A positive displacement unit as claimed in any of claims 13 to 15 inclusive, wherein the two pairs of rotors have different volumetric displacement, the rotor pair of smaller displacement is part of a compressor, a first duct is provided for admitting air to said compressor, a second duct is provided for conducting compressed air from said compressor to a combustion chamber through an opening adjacent the periphery of the compressor rotors, means is provided for changing the opening to control the compressor ratio, a third duct is provided for conducting combustion gas from said chamber to the other pair of rotors, and a fourth, exhaust duct is provided for conducting the expanded combustion gas from said other pair of rotors to the outside.
17. A process for producing a toothed rotor, as claimed in any one of the preceding claims, for a positive displacement unit, comprising rotating a rotor blank continuously on its axis while imparting a working motion to a tool, effecting a relative feed motion between tool and blank about an axis which intersects the axis of the blank, so that the tool moves from the top to the bottom of a tooth and then from the bottom to the top of the tooth.
18. A process as claimed in claim 17, wherein the axis of feed is at right angles to the axis of the blank, and the feed motion takes place from the top to the bottom and then back to the top of each tooth.
19. A process according to either claim 17 or claim 18, wherein the rotation of the blank about its axis is at a varying speed during production of each tooth.
20. A process according to any of claims 17 to 19 inclusive wherein the tool is a milling cutter whose cutting edges lie in a conical surface whose axis coincides with the axis of the cutter.
21. A process according to any of claims 17 to 20 inclusive wherein the tool is a reciprocating tool with a rounded working profile, the feed motion between the tool and blank being varied for each tooth so that a predetermined point of the tool profile describes a mean tooth profile, and displacing the tool during production of each tooth side to keep engaging the tooth profile continuously at said point.
22. A process according to claim 21, wherein the working profile of the tool has a varying curvature, with the largest curvature at the point which comes into contact with tooth bottom.
23. A positive displacement unit substantially as described herein with reference to the accompanying drawings.
24. The process of producing a rotor as claimed in any one of claims 1 to 16, for a positive displacement unit substantially as described herein.

JENSEN & SON,

Agents for the Applicant,  
77 Chancery Lane,  
London, W.C.2.  
Chartered Patent Agents.





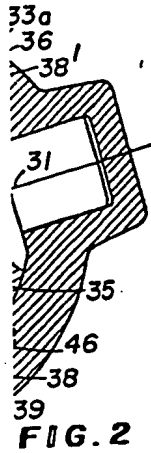


FIG. 3

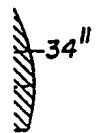


FIG. 5

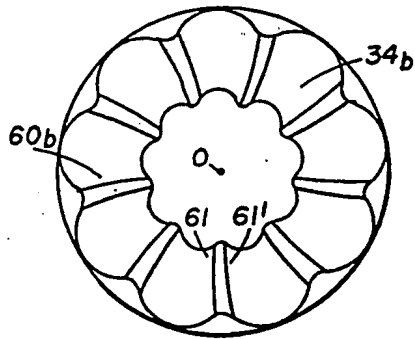


FIG. 7

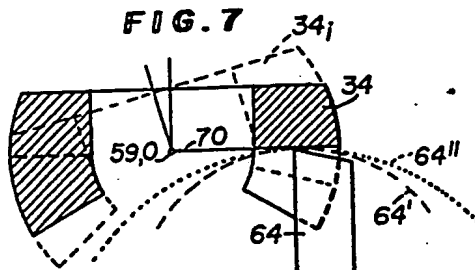


FIG. 10

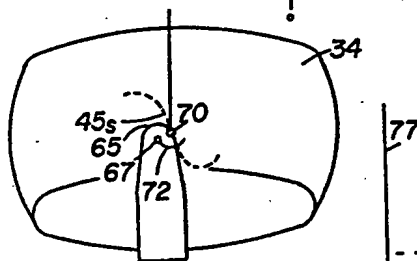


FIG. 12

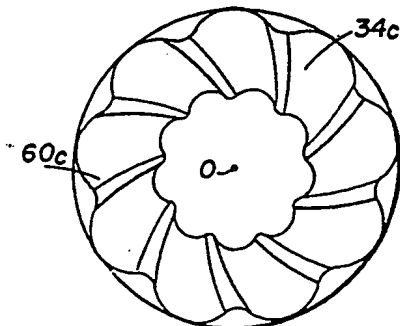


FIG. 8

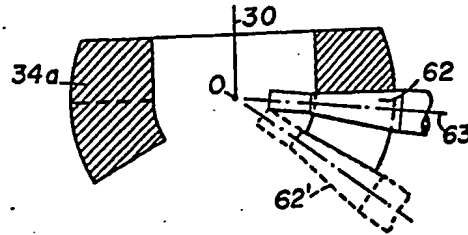


FIG. 9

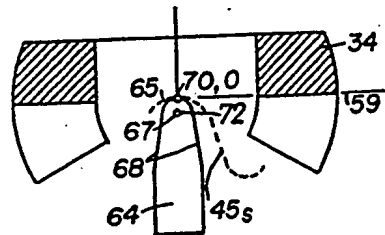


FIG. 11

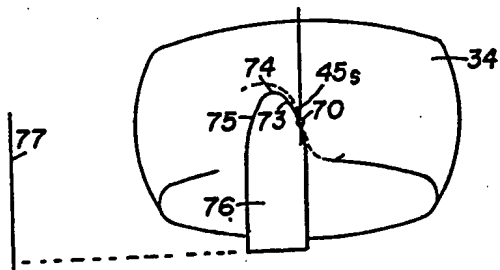


FIG. 13

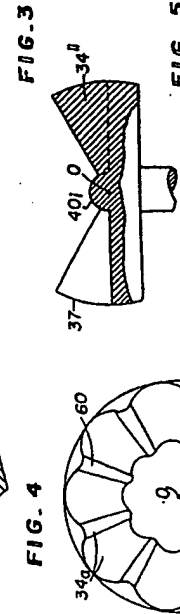
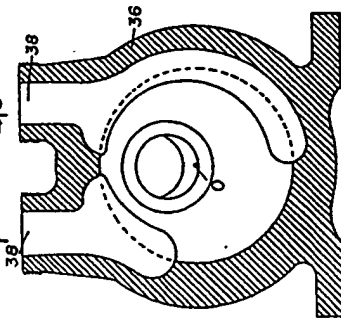
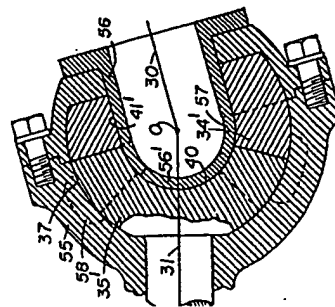
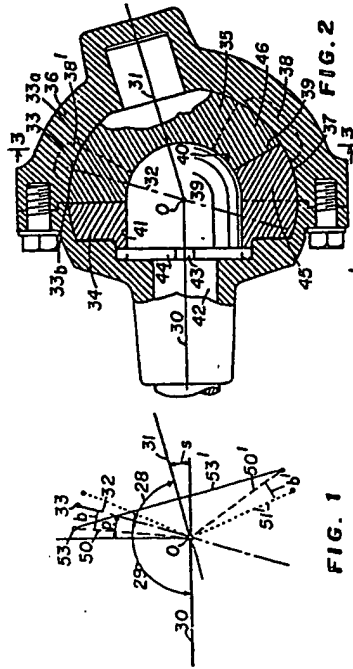


FIG. 5

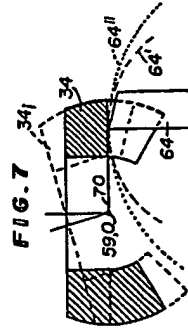
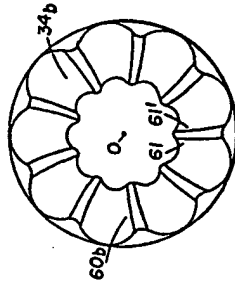
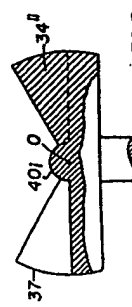


FIG. 9

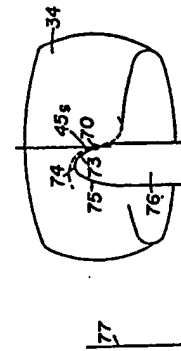
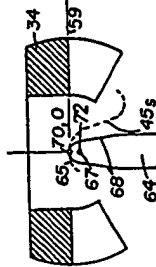


FIG. 12

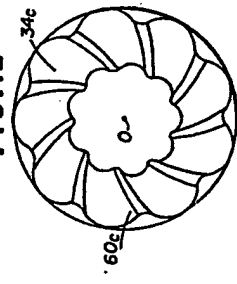
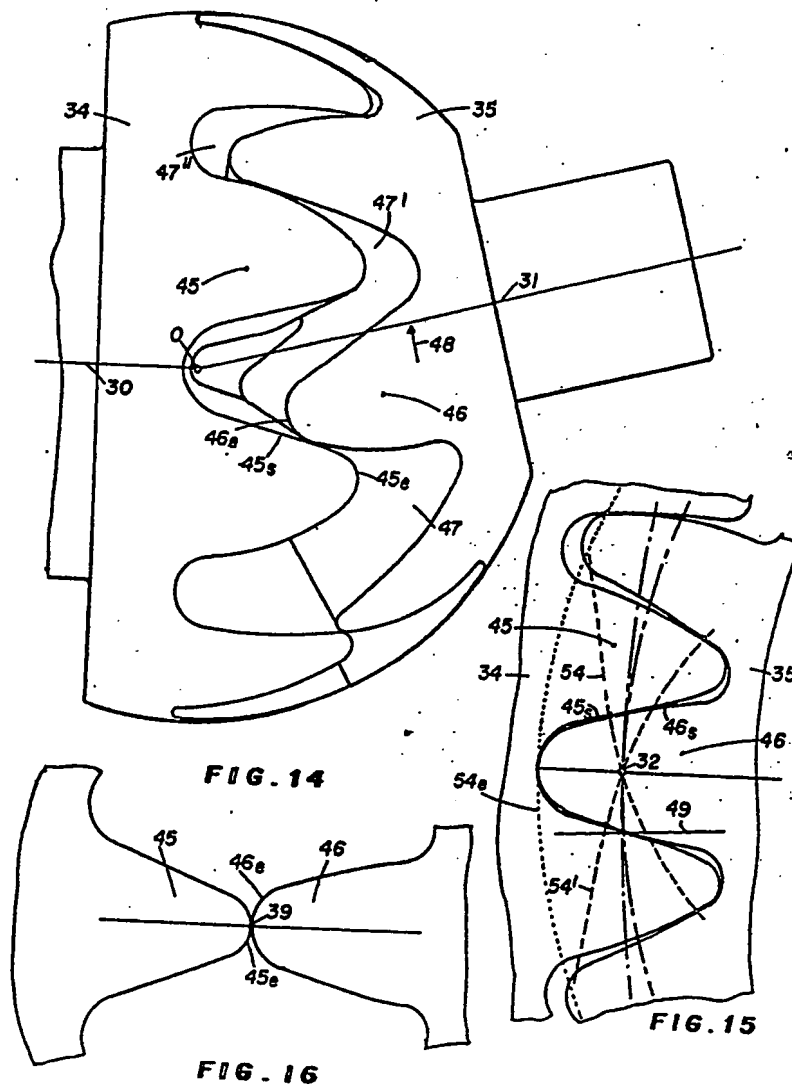


FIG. 14

FIG. 15



1,099,085

COMPLETE SPECIFICATION

4 SHEETS

This drawing is a reproduction of  
the Original on a reduced scale.

SHEETS 3 & 4

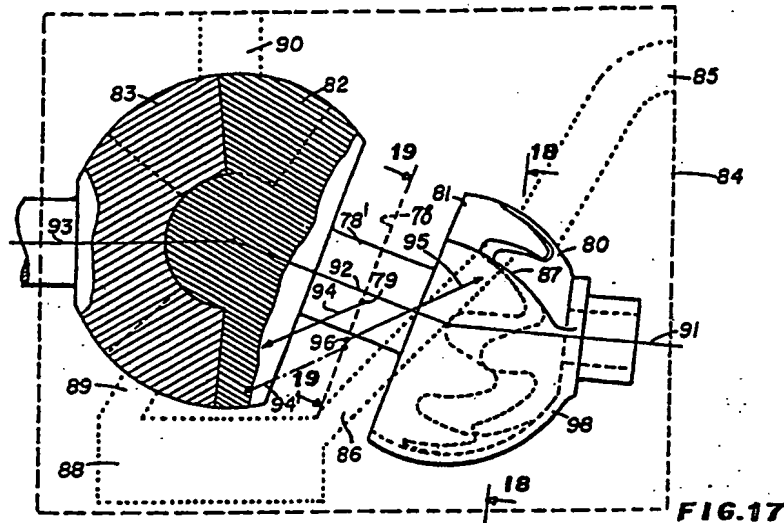


FIG. 17

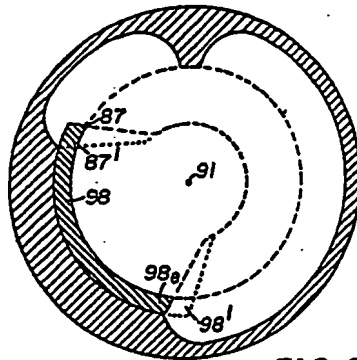


FIG. 18

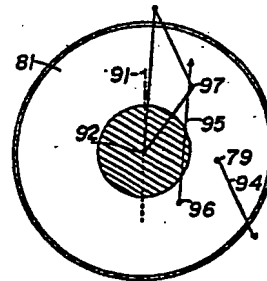


FIG. 19

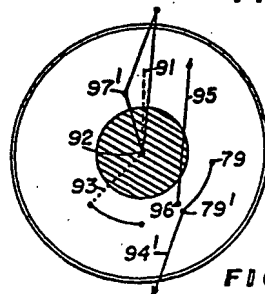


FIG. 20

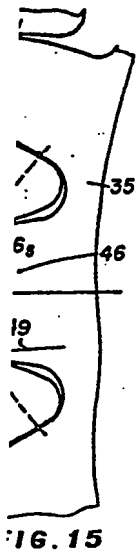


FIG. 15

1,099,085 COMPLETE SPECIFICATION  
 4 SHEETS  
 This drawing is a reproduction of  
 the Original on a reduced scale.  
 SHEETS 3 & 4

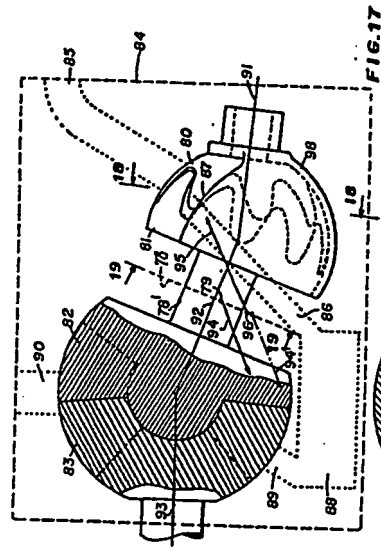


FIG. 17

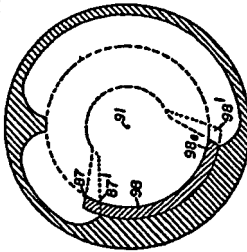


FIG. 18

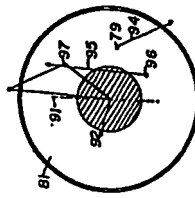


FIG. 19

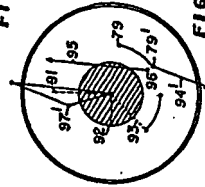


FIG. 20

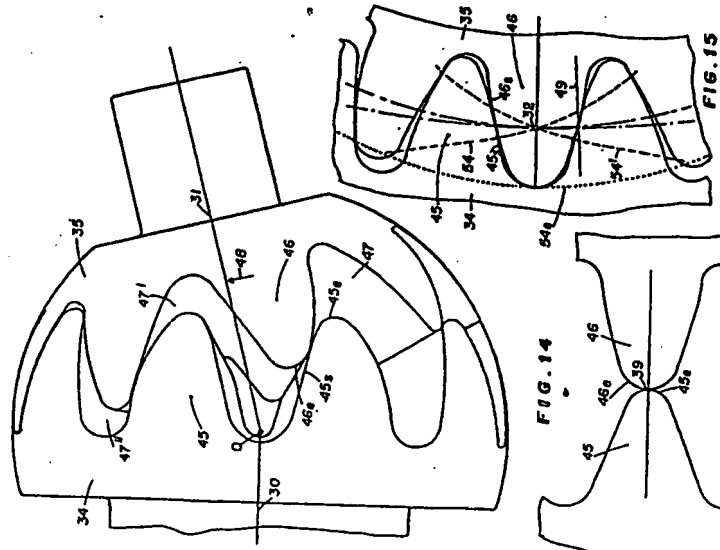


FIG. 14

FIG. 15

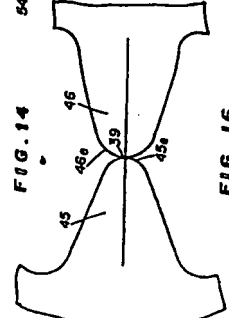


FIG. 16

**This Page is Inserted by IFW Indexing and Scanning  
Operations and is not part of the Official Record**

**BEST AVAILABLE IMAGES**

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☐ BLACK BORDERS
- ☒ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☐ FADED TEXT OR DRAWING
- ☐ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☒ SKEWED/SLANTED IMAGES
- ☐ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☒ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☐ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: \_\_\_\_\_

**IMAGES ARE BEST AVAILABLE COPY.**

**As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.**